

DC-GHz Micromachined Capacitive Air Transducers



B. T. Khuri-Yakub
F. L. Degertekin
A. S. Ergun

E. L. Ginzton Laboratory
Stanford University
Stanford CA, 94305-4085

Outline

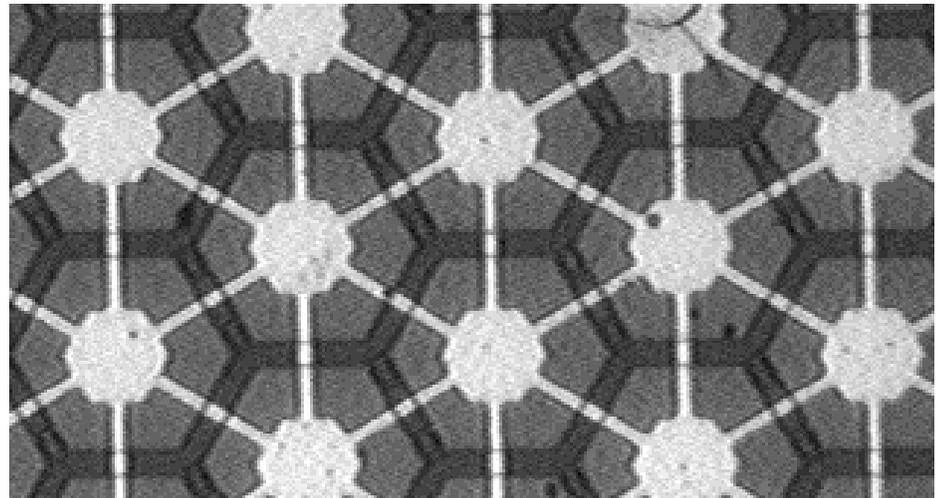
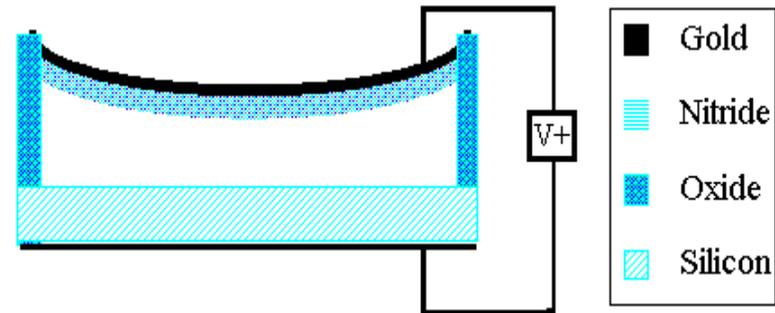


- Introduction and Approach
- Traditional detection and performance of resonant capacitor transducers
- Broad band detection and potential improvement in sensitivity
- Conclusions

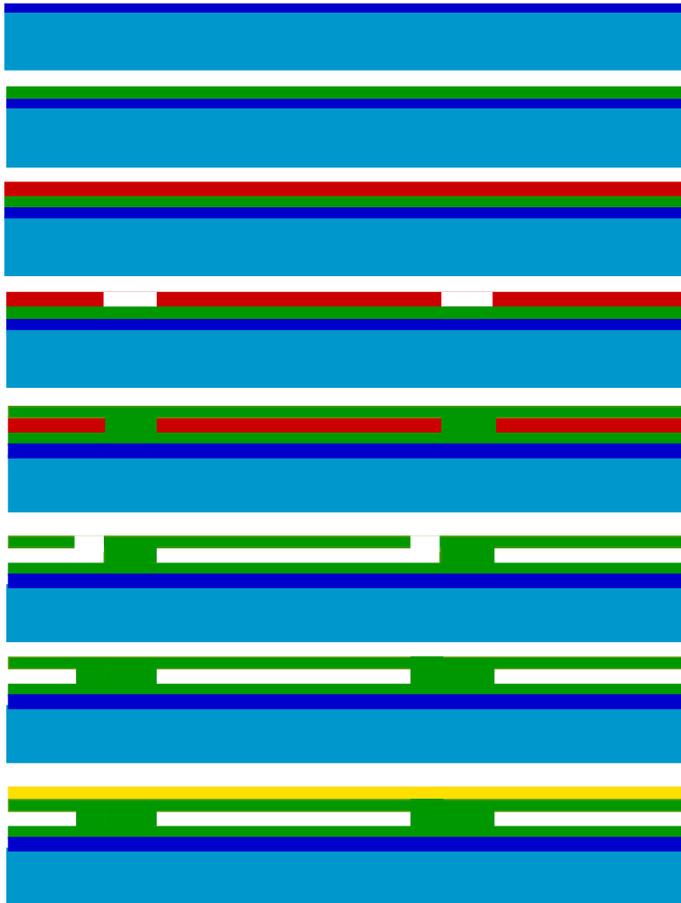
Capacitor Micro-machined Ultrasonic Transducer (cMUT)



- Thin ($\sim 1 \mu\text{m}$), $50 \mu\text{m}$ radius, metalized nitride membranes suspended above silicon substrate.
- Several thousand electrically connected in parallel form the transducer.
- Resonant structure has dynamic range in excess of 100 dB.
- Electric field 10^9 V/m

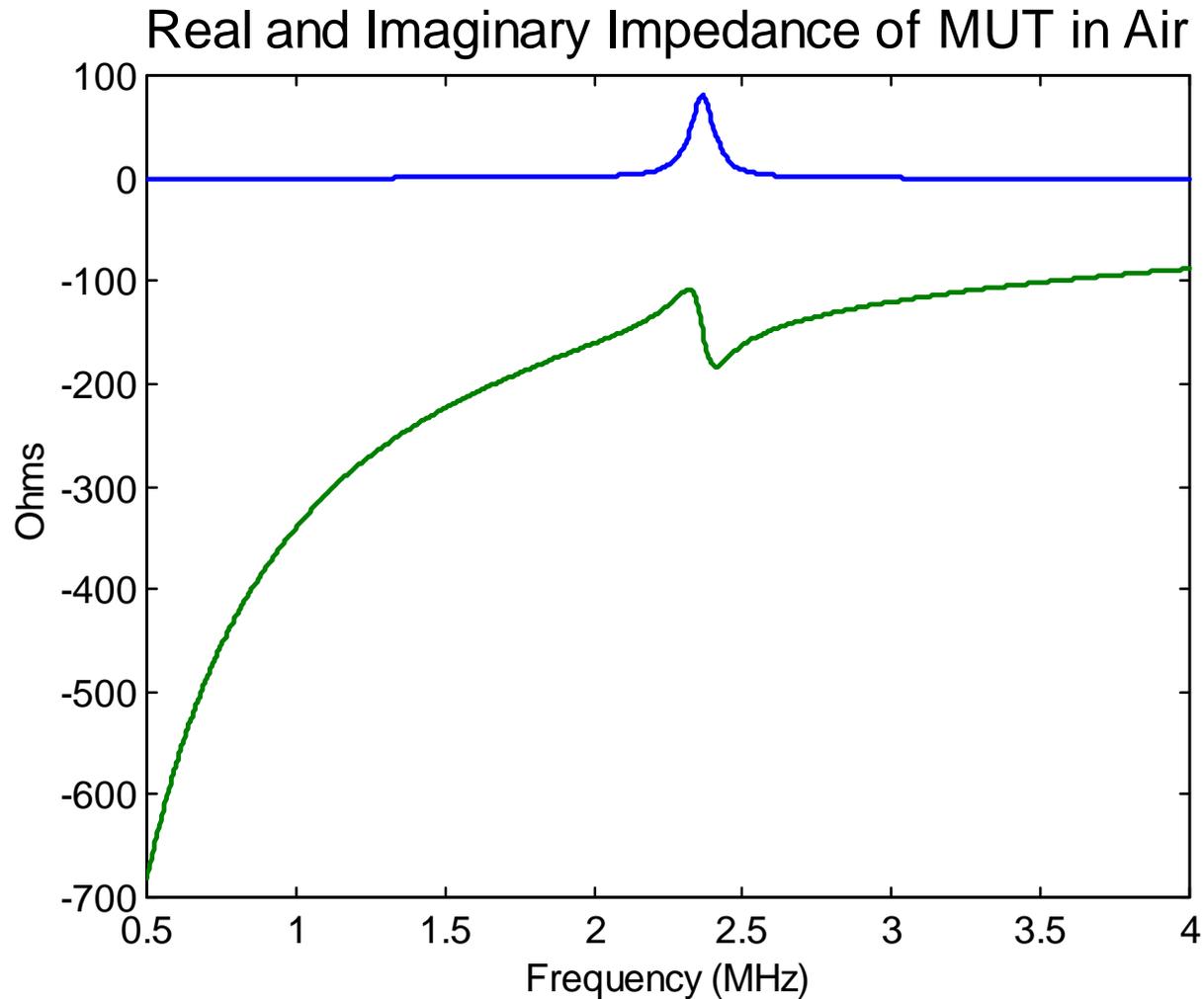


Fabrication Process



- High density doping
- LPCVD nitride deposition
- Amorphous silicon deposition
- Lithography and etch
- LPCVD nitride deposition
- Via and sacrificial etch
- Vacuum sealing
- Metal deposition and patterning

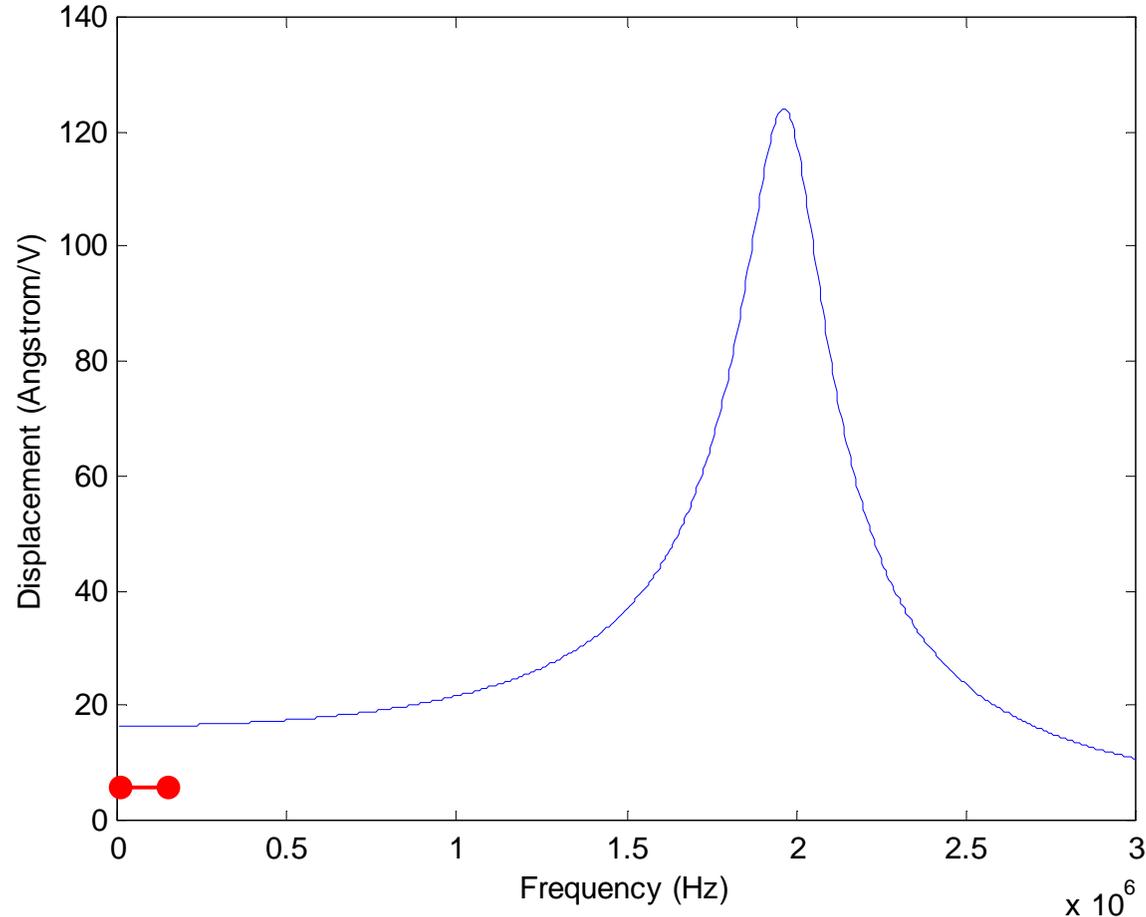
Input Impedance of cMUT in Air



Average Displacement of a Membrane



Displacement vs. Frequency $V_{dc} = 213$ V, $V_{collapse} = 213.3032$ V, $C_{device} = 361.7644$ pF

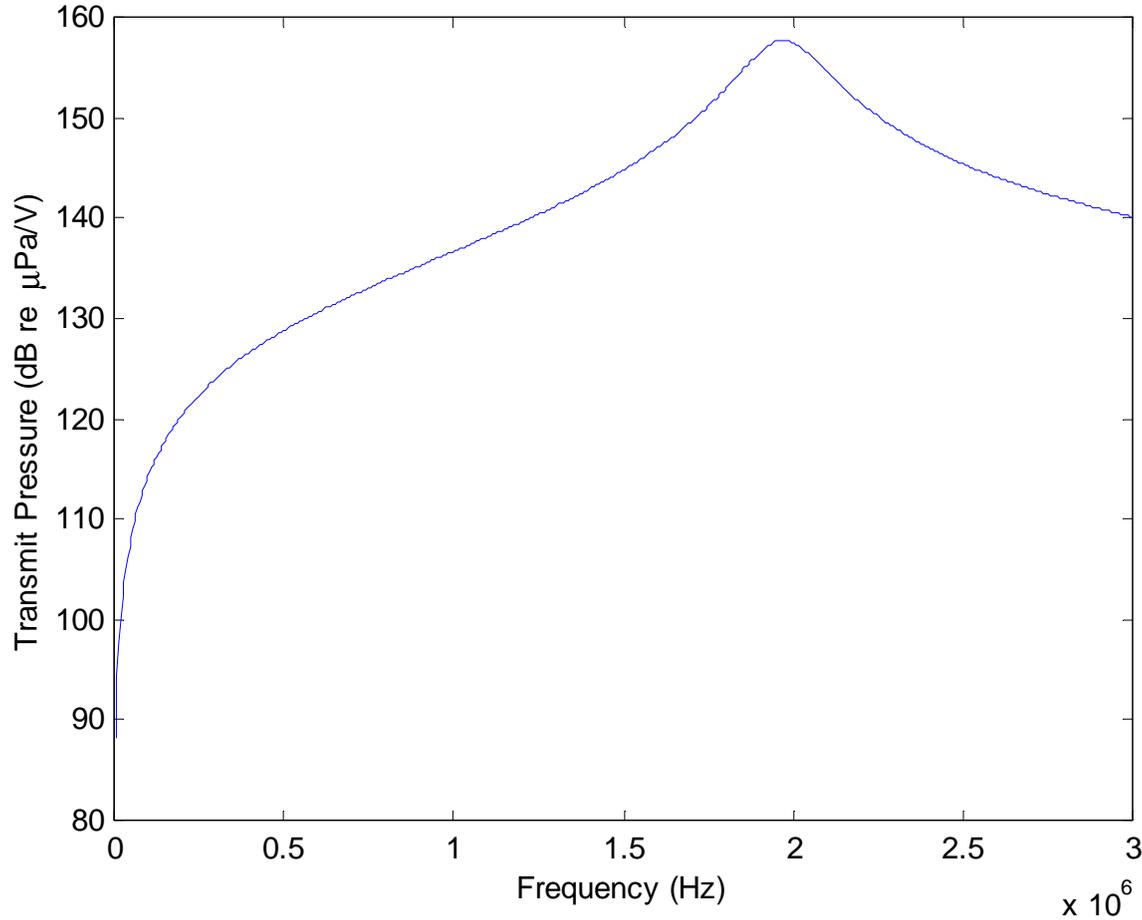


Broad band operation below resonance

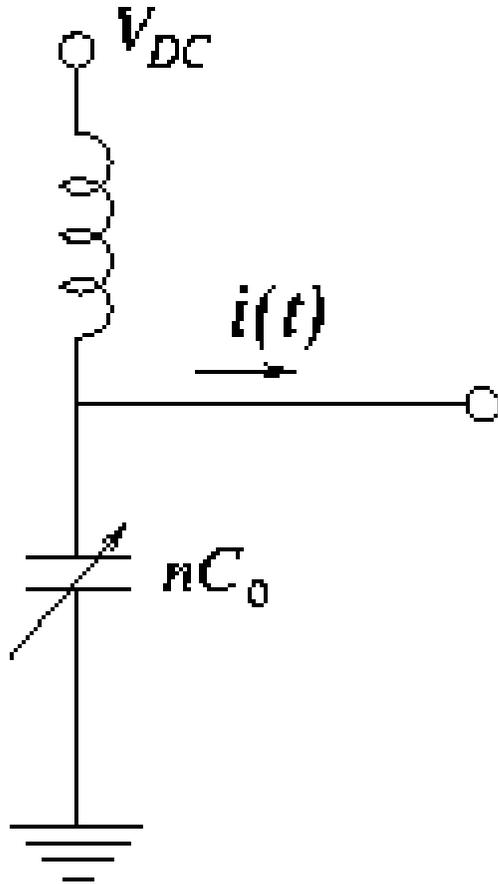


Transmit Pressure of cMUT

Transmit Pressure vs. Frequency; $V_{dc} = 213$ V, $V_{collapse} = 213.3032$ V, $C_{device} = 361.7644$ pF



Conventional Detection



$$I_{out} = V_{DC} 2\pi f_1 nC_0 \frac{\Delta x}{x_0}$$

Receive Output of Conventional Detection Method



1cm x 1cm X-ducer

Membrane:

50 μ m diameter

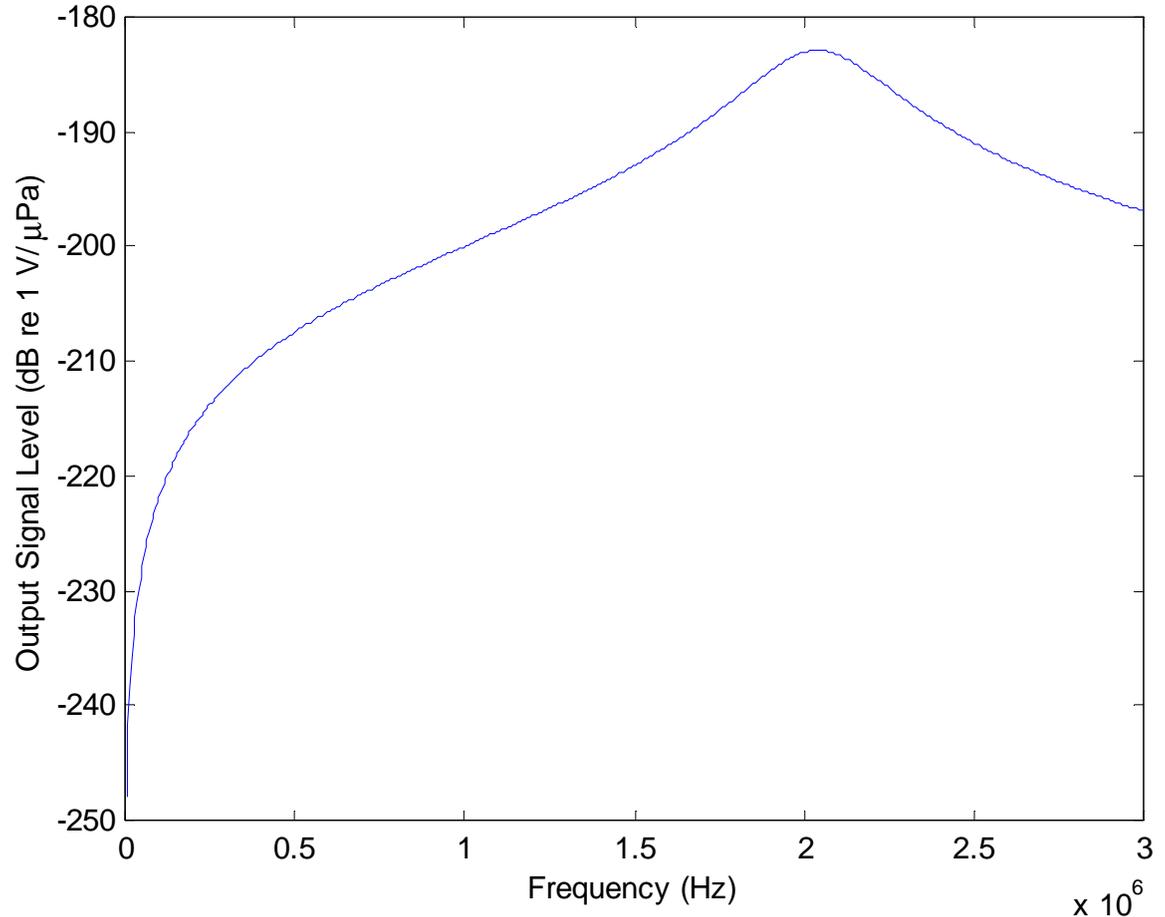
1 μ m gap

1 μ m thickness

Silicon Nitride

20% Parasitic C

Output Signal Level vs. Frequency $V_{dc} = 213$ V, $V_{collapse} = 213.3032$ V, $C_{device} = 361.7644$ pF



Signal to Noise Ratio of Receiver



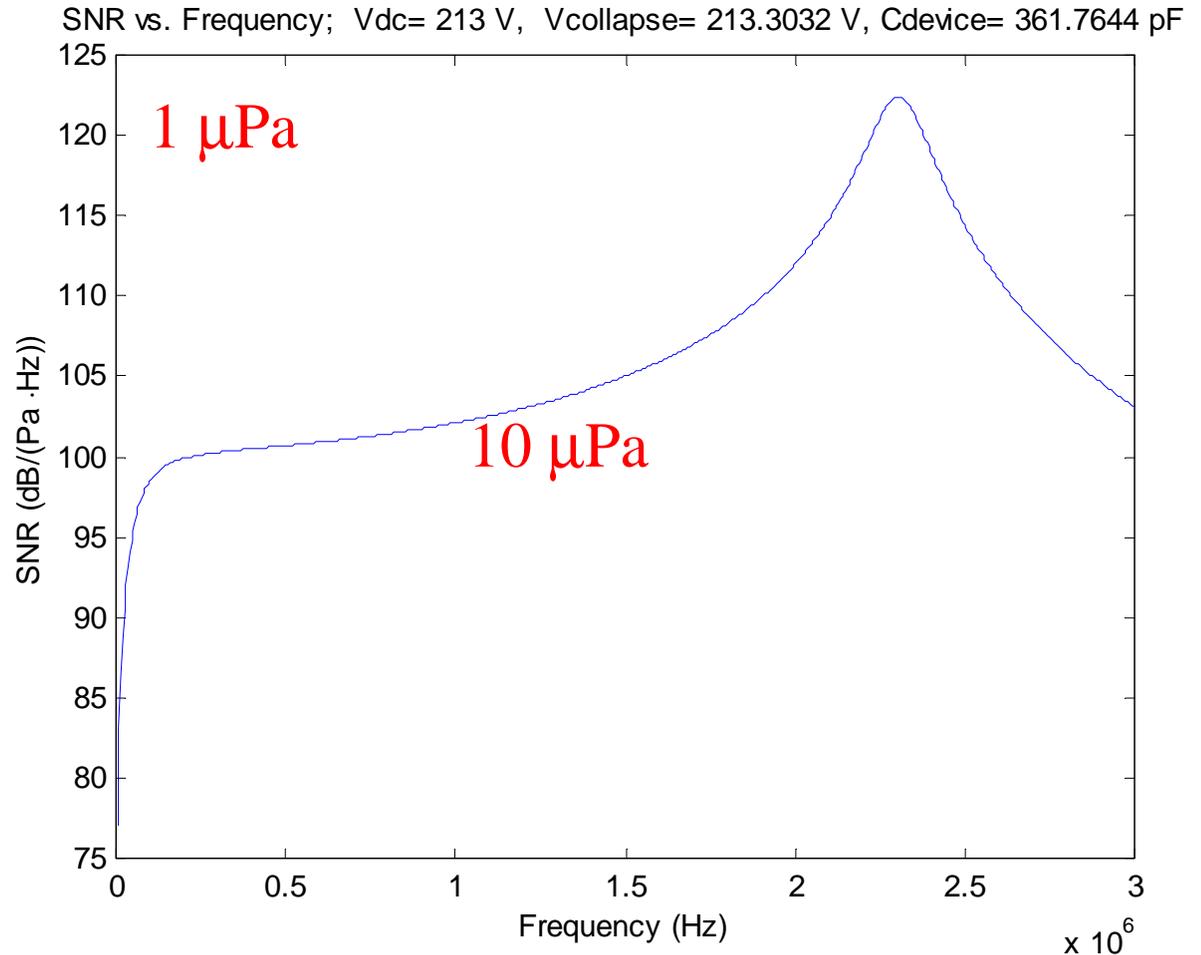
Amplifier:

$$R_{in} = 100 \text{ } \hat{U}$$

$$C_{in} = 1 \text{ pF}$$

$$V_{na} = 1.4 \text{ nV}/\sqrt{\text{Hz}}$$

$$I_{na} = .01 \text{ pA}/\sqrt{\text{Hz}}$$

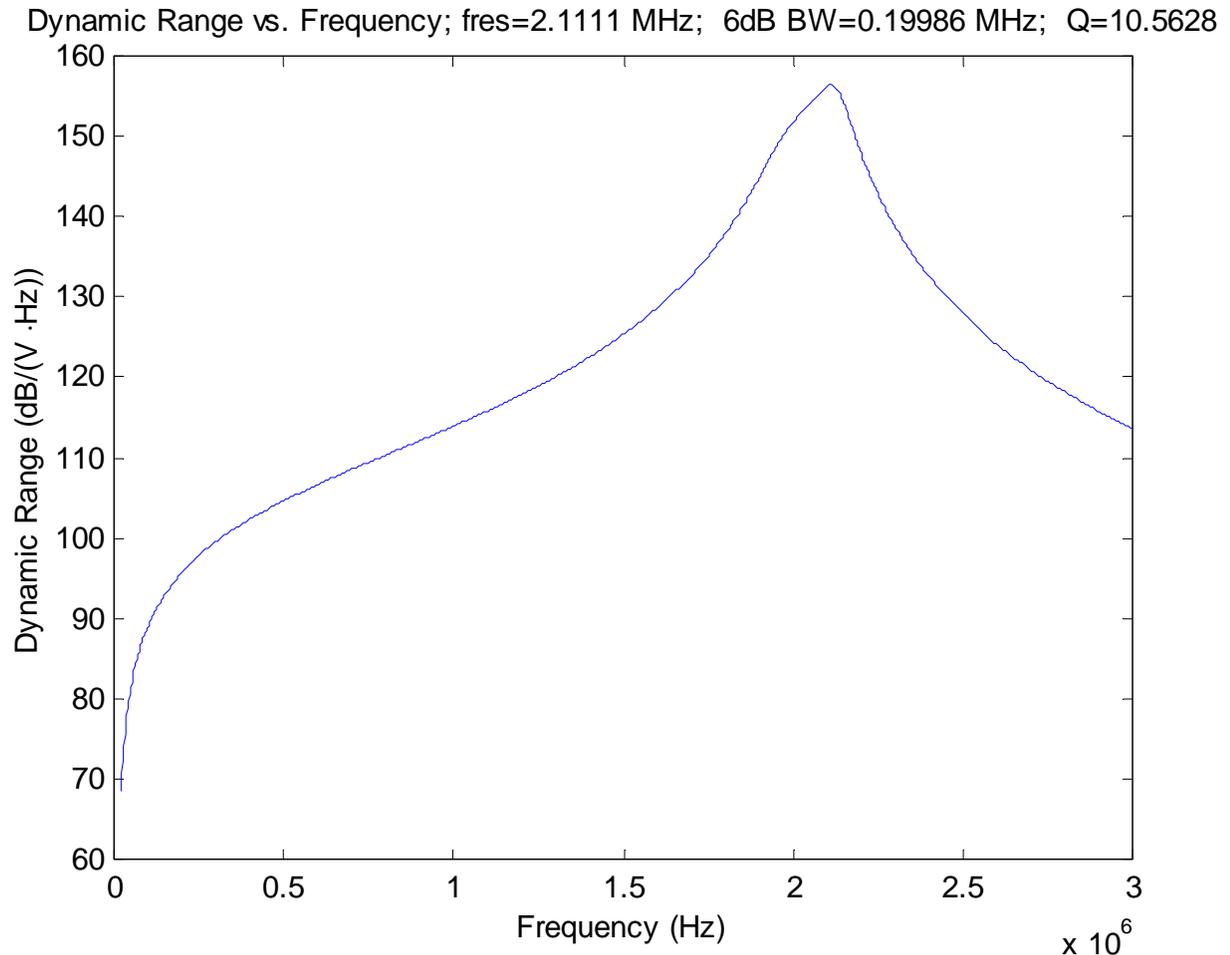


Dynamic Range of cMUT Air Transducer System

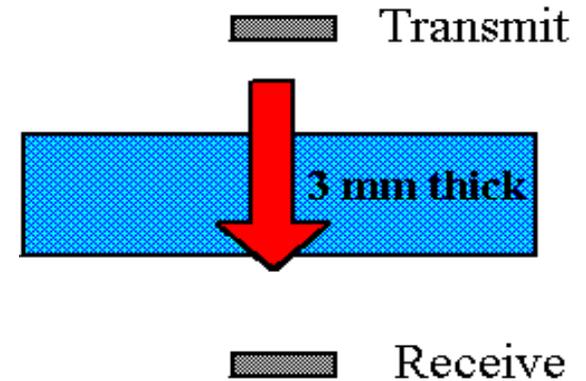
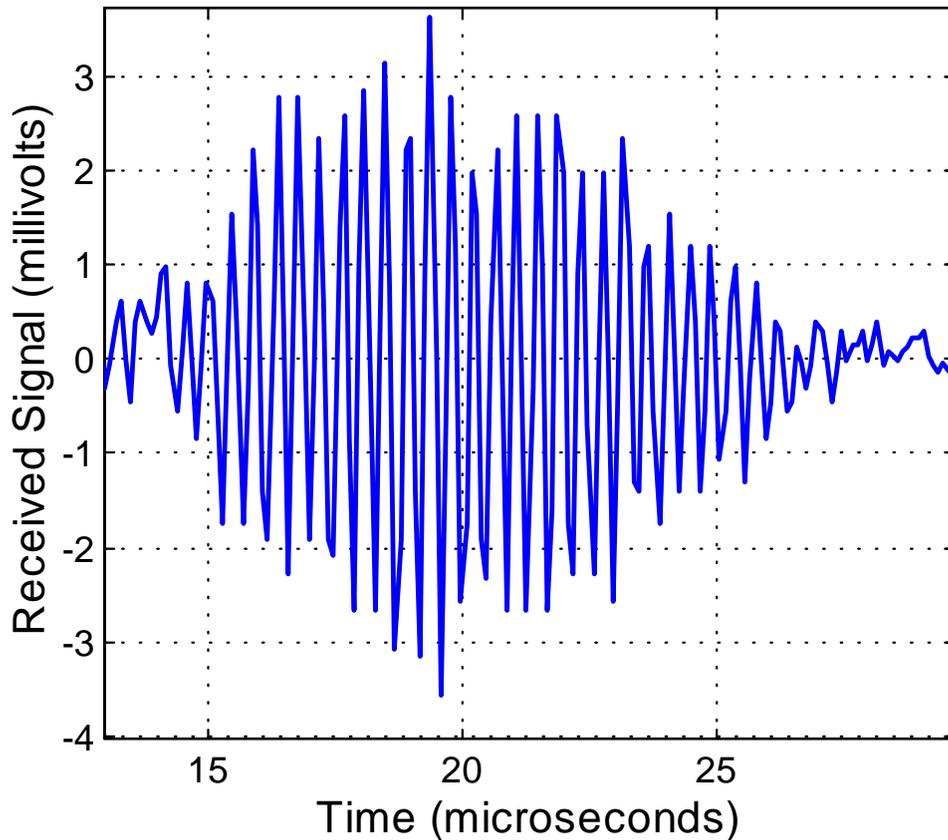


Transmitter:
Source $R = 50 \Omega$

Receiver:
Previous slide



Transmission Through Aluminum at 2.3 MHz

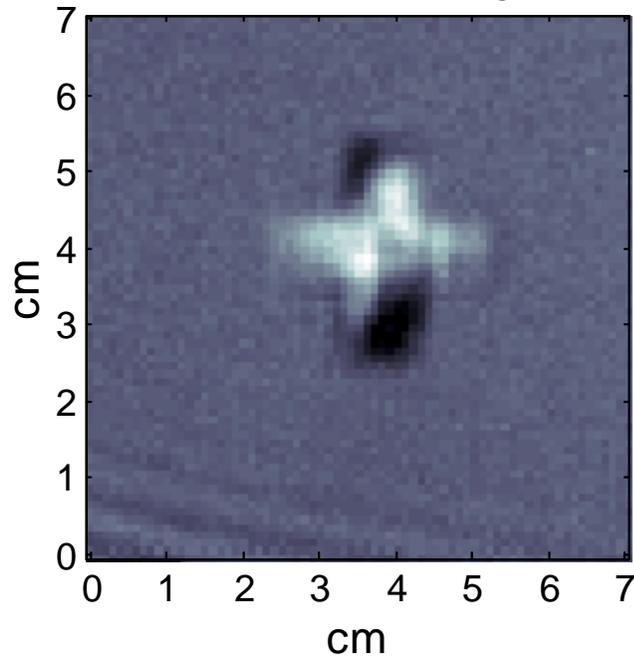


82 dB loss in 3 mm Al
16 dB SNR
+ 5 dB loss in 0.6 cm air
103 dB System
Dynamic Range

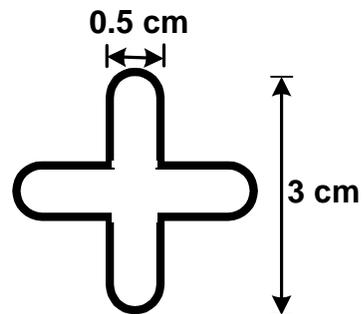
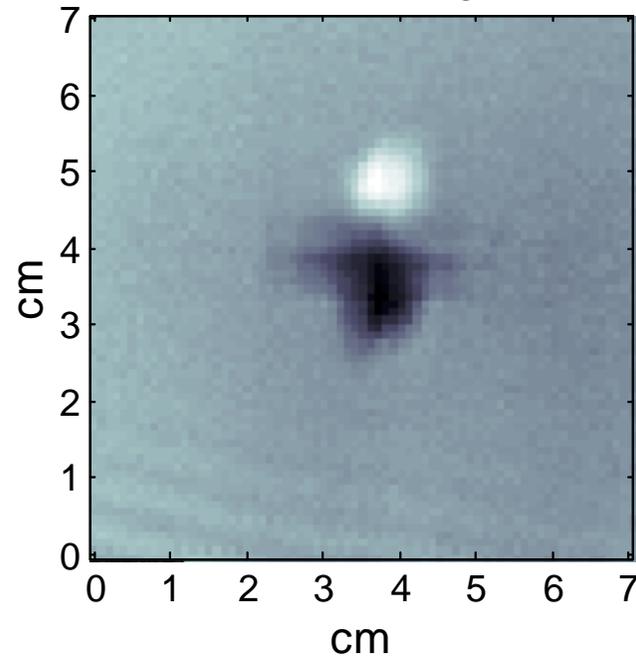
Transmission Image of Aluminum



Amplitude image



Phase image

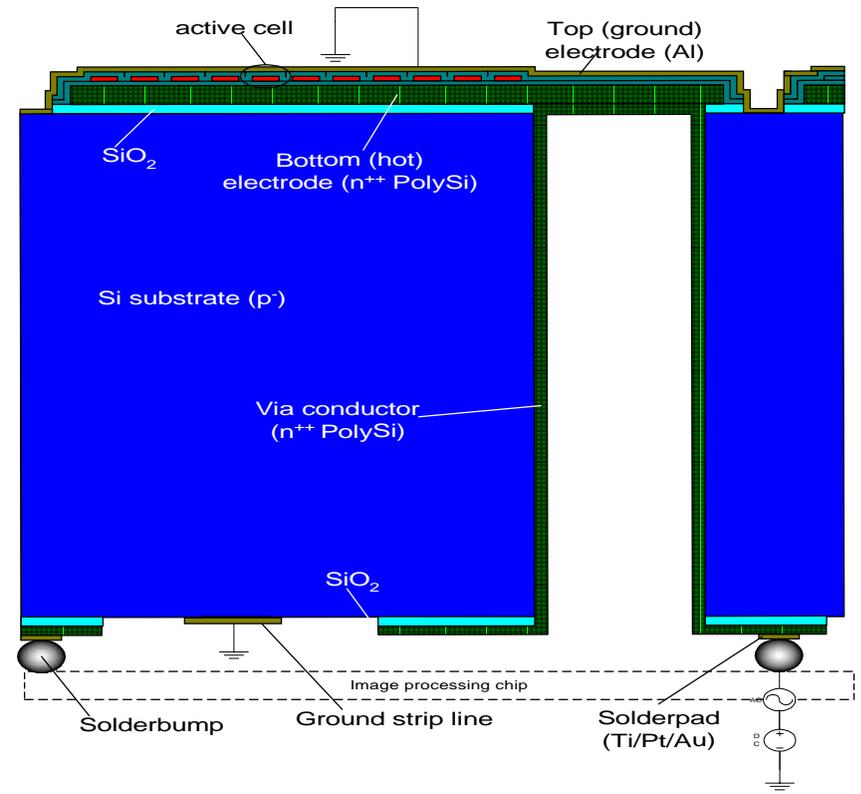
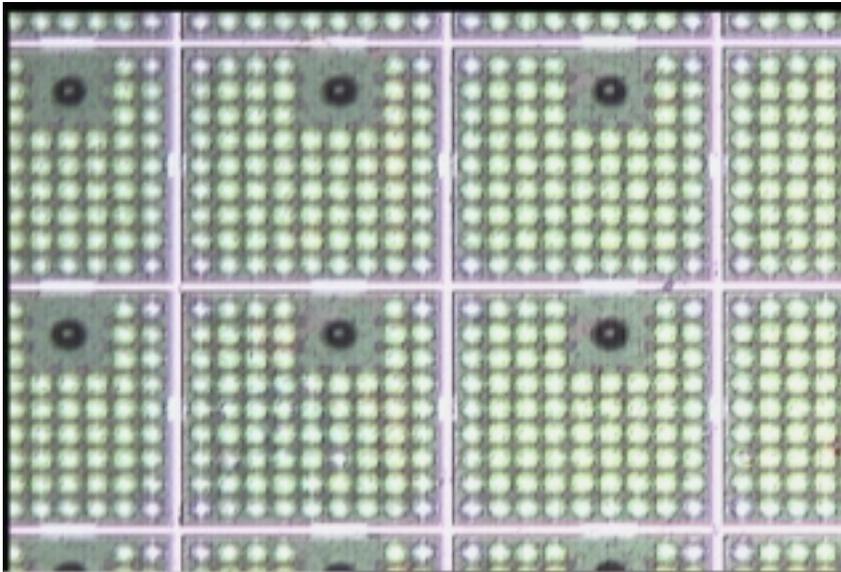


0.5 mm deep milled pattern
on underside of 3 mm thick
aluminum

Accomplishments of Present Technology



- Large dynamic range systems from **800 kHz - 11 MHz**
- Single element, 1-D and 2-D arrays
- Through wafer contact vias
- Flip-chip bonding to integrate ultrasonics and electronics

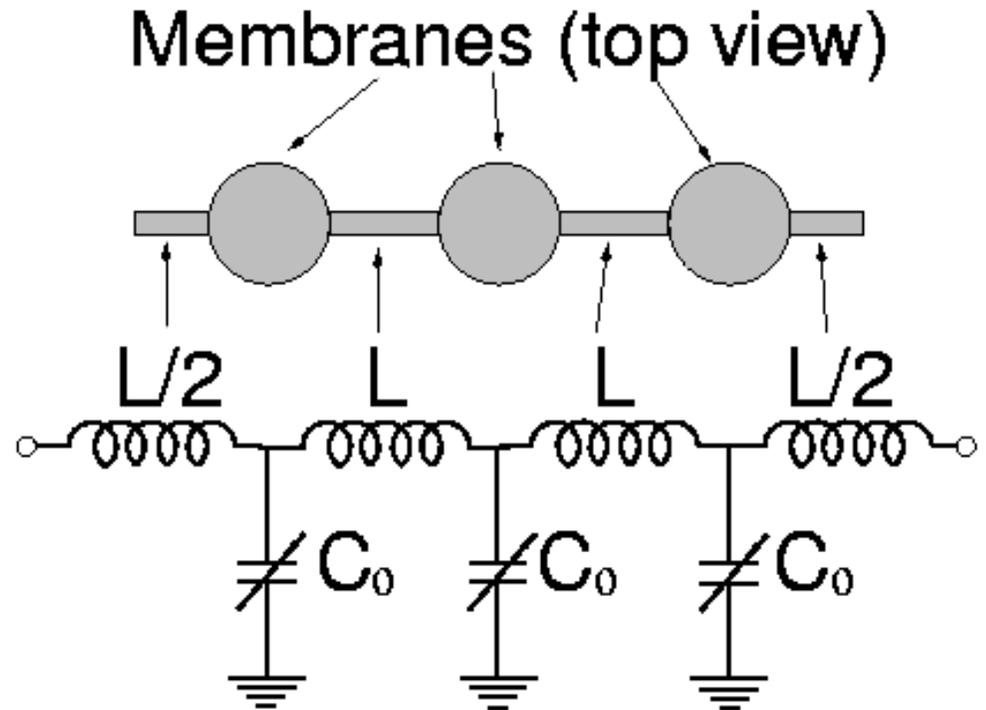


Broadband Detection: cMUTs as Elements of a Transmission Line



$$Z_a = \sqrt{\frac{L}{C_0}}$$

$$\beta = 2\pi f_0 \sqrt{LC_0}$$



Incident sound wave modulates the phase of an HF signal applied to the transmission line.

Comparison of Conventional and Broadband Detection Schemes



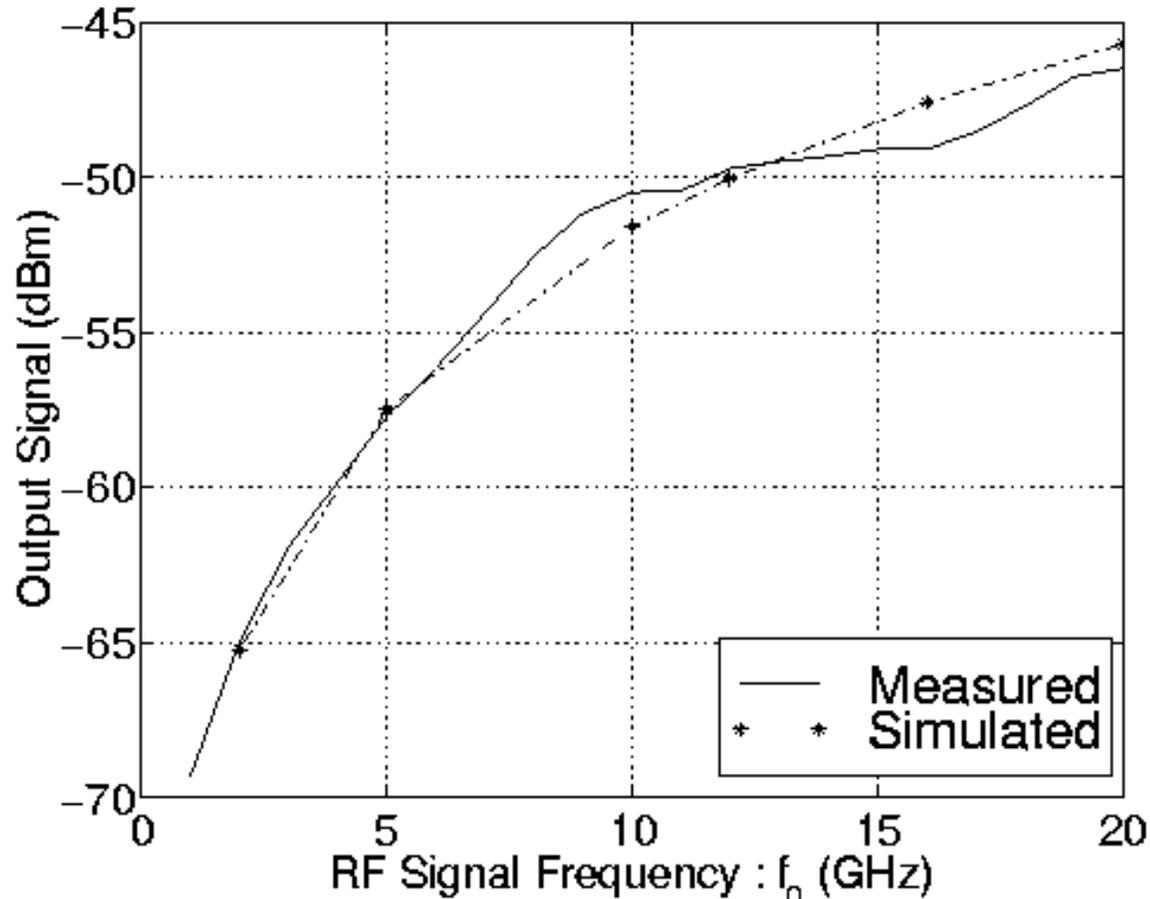
$$I_{out} = V_{DC} 2\pi f_1 n C_0 \frac{\Delta x}{x_0}$$

$$I_{out} = \frac{V_{RF}}{4} 2\pi f_0 n C_0 \frac{\Delta x}{x_0}$$

- Higher Sensitivity
- Broadband
- No dc necessary
- The lower the frequency, the better the sensitivity

Variable	Typical
V_{RF}	2 V
V_{DC}	100 V
f_0	10 GHz
f_1	0.1 MHz
Ratio	500

Broadband Detection: Experimental Results



Courtesy of Ergun and Atlalar (Bilkent University)

Conclusions



- Surface micromachining can achieve low frequency (20-200 kHz) receivers.
- A broadband detection scheme allows operation over dc-GHz range.
- 1-D and 2-D arrays enable direction sensing.
- Through wafer vias enable integration to electronics via flip-chip bonding.